ANALYSIS AIDS FOR THE AMERICAN TROPICS

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[Manuscript received February 12, 1958; revised April 14, 1958]

ABSTRACT

Analysis of upper-level charts for the American Tropics, which is a largely oceanic area, is difficult because data are inadequate and are likely to remain so in the foreseeable future. Despite this handicap and the unsatisfactory character of the map, the 500-mb. analyses are routinely used for many different tropical forecasting procedures. Some aids are suggested for improving the analyses that are made to meet this continuing requirement.

Since the lower troposphere is somewhat barotropic, pressure-height changes at 700 mb. and 500 mb. are largely a function of sea level pressure change so that a careful surface analysis along with a good differential analysis can yield great improvement in upper-air analysis compared to a straightforward analysis of upper-air data.

Maps of normal thicknesses, 1000–700 mb., 700–500 mb., and 1000–500 mb., based on all constant pressure data from the American Tropics are presented for the hurricane season. Statistics relative to these fields of thickness such as 24-hour changes, correlation between the upper and lower strata, and typical anomaly patterns, are included and discussed. In addition, several indicators of anomaly which are useful in higher latitudes were investigated and found to be of limited value in this area.

Finally it is concluded that tropical maps must be re-analyzed as late data become available and that analyses must be made under the control of thermal and time-continuity restraints discussed here.

1. INTRODUCTION

Perhaps the greatest single obstacle to research and forecast development in the Tropics is the deficiency of observations and the consequent uncertainty in our description of the atmosphere. It is patently absurd to expect improvement in forecasting some *future* state of the atmosphere until it is possible to obtain a reasonably accurate knowledge of its *initial* state.

Because our tropical region is largely oceanic, the problem of adequate observations will not be solved in the foreseeable future, but some improvement in analysis can be realized by a careful and unremitting use of all climatology and knowledge available to us.

The fundamental question of utility of pressure contour analysis in the Tropics is outside the scope of this paper. There is little doubt however, that pressure analysis by itself in low latitudes is inadequate, for it is but a blurred and distorted reflection of the field of motion, and the 500-mb. surface is particularly unsatisfactory in many situations. Despite their shortcomings, 500-mb. data are used routinely as input for numerical weather predictions and for hurricane motion computations, so there is an immediate demand for the best possible 500-mb. analysis. In addition there are other methods of analyzing tropical data under study (e. g., [1]) which must ultimately take account of the pressure gradient because the pressure field represents an important force that cannot be neglected.

The primary purpose of this paper is to present monthly mean thicknesses for the American Tropics during the hurricane season, and in addition some upper-air synoptic climatology is included which will help in the use of mean thicknesses in preparation of 700- and 500-mb. analyses.

The statistics are by no means exhaustive nor are they based on the maximum number of samples, with the exception of the thicknesses, but it was felt that a report even of this limited scope should be circulated because up to this time no such material has been available.[1] Too, the value—indeed the necessity—of differential analysis in the Tropics needs to be emphasized. Wherever the density of surface reports is greater than that of the upper-air network, vertical extrapolation is worthwhile. Not to consider *every single* surface report while analyzing the 700-mb. and 500-mb. maps is to ignore expensive observations that are as important as radiosonde observations. In practice a convenient procedure is to consider every surface report in constructing a 1000-mb. chart and extrapolate to the desired pressure-height in regions of no upper-air data.

2. DATA USED

The charts of mean thicknesses (700 mb.–1000 mb. is referred to as ΔH_1, 500 mb.–700 mb. as ΔH_2, and 500 mb.–1000 mb. as ΔH_3 in the following pages), figures 6 through 15, are based on all available constant pressure data of the American Tropics. Table 1 shows the stations and period of record used. The statistics are not based on upper-air analyses because over this area there is an unknown amount of human error and bias.

The thicknesses at the Islands of Sal and Funchal are shown, when available, as insets to figures 6–15, but because such a large expanse of data-free ocean exists between those stations and our network, it was impossible to extend a reliable analysis eastward.

The thicknesses shown in parentheses are considered to be of a lower order of accuracy than the remaining ones,

[1] Similar normals have been published [2, 3] but the emphasis has been on the mid-latitudes so they are of limited utility for tropical analysis.

TABLE 1.—*Radiosonde records used in computation of mean thicknesses*

Location	Number of observations*				
	July	August	September	October	November
	0300 GMT				
Antigua, B.W.I.	48	24	27	42	40
Balboa, C. Z.	241	257	271	255	271
Bermuda	282	289	262	279	264
Brownsville, Tex.	278	262	266	277	266
Burrwood, La.	278	262	266	277	266
Charleston, S. C.	279	278	268	279	270
Funchal, Madeira Islands	-----	-----	-----	-----	-----
Georgetown, British Guiana	13	26	36	40	33
Hatteras, N. C.	278	276	270	277	269
Havana, Cuba	233	244	244	242	263
Maracay, Venezuela	4 yr.	3 yr.	4 yr.	3 yr.	4 yr.
Merida, Yucatan	9 yr.	8 yr.	7 yr.	8 yr.	8 yr.
Miami, Fla.	276	277	267	274	269
St. Lucia, B. W. I.	-----	2	16	31	29
Sal Island (22.9° N., 16.7° W.)	8 yr.	7 yr.	8 yr.	7 yr.	8 yr.
San Juan, P. R.	277	271	266	274	266
Ship E (35° N., 48° W.)	243	233	240	269	270
Swan Island	253	268	261	247	235
Trinidad, B. W. I.	132	152	151	159	129
Vera Cruz, Mexico	9 yr.	8 yr.	6 yr.	7 yr.	7 yr.
	1500 GMT				
Antigua, B. W. I.	37	26	37	46	43
Balboa, C. Z.	227	260	271	254	269
Bermuda	274	287	259	282	278
Brownsville, Tex.	276	276	266	278	268
Burrwood, La.	271	263	263	276	267
Charleston, S. C.	279	279	270	279	269
Funchal, Madeira Islands	6 yr.	6 yr.	6 yr.	6 yr.	5 yr.
Georgetown, British Guiana	16	25	32	40	46
Hatteras, N. C.	278	277	270	276	269
Havana, Cuba	226	246	248	242	266
Maracay, Venezuela	4 yr.	3 yr.	4 yr.	3 yr.	4 yr.
Merida, Yucatan	-----	-----	-----	-----	-----
Miami, Fla.	279	279	266	276	270
St. Lucia, B. W. I.	12	29	30	31	29
Sal Island (22.9° N., 16.7° W.)	-----	-----	-----	-----	-----
San Juan, P. R.	273	277	267	277	266
Ship E (35° N., 48° W.)	240	233	241	270	268
Swan Island	259	270	264	240	229
Trinidad, B. W. I.	123	184	179	171	134
Vera Cruz, Mexico	5 yr.	5 yr.	5 yr.	5 yr.	5 yr.

* "9 yr." indicates 9 monthly means for that month were averaged.

either because of a short period of record or because they were adjusted to correct for a systematic error that appeared when the means were analyzed for homogeneity. For example, the thicknesses at Miami, Fla., and Merida, Yucatan were adjusted to correct for systematic errors that have since been corrected.

Since the nighttime soundings have little radiation error, the 0300 GMT maps of ΔH_1 and ΔH_2 were analyzed first; then maps of 12-hour changes were prepared in order to obtain smooth and reasonable change patterns.[2] This procedure indicated the data which apparently had systematic daytime errors and the 1500 GMT thicknesses were adjusted. The ΔH_3 charts were then constructed by addition of ΔH_1 and ΔH_2.

Figures 6–15 inevitably include a certain amount of subjectivity. For example, the large area east of the Windward Islands is completely innocent of data just where general considerations indicate the greatest thicknesses occur. The actual maximum values are of course unknown but in each case they were estimated from the frequency distribution of thicknesses at San Juan, modified where necessary by the constraint of a reasonable space gradient. This involves the assumption that distribution in time is quite similar to distribution in space; i. e., if a large number of observations of a given thickness appeared at San Juan during a given month, those values were assumed to have existed elsewhere in space during the same month when some other thickness was observed at San Juan. Since the oceanic High is frequently displaced westward over San Juan it was assumed the large thicknesses were advected from the east. For example, figure 6A shows a large area of ΔH_1 of 3050 meters and a small maximum of 3055 meters. During that month the frequency distribution at San Juan had a mean of 3046 meters, but 31 percent of the thicknesses were in the class interval 3048 to 3055 meters and another 16 percent were greater than 3055 meters, and a "reasonable" gradient of thickness was not inconsistent with a maximum value of 3055 meters.

[2] The 12-hour change charts are not included here because they are of limited usefulness with the new observation times. Upper-air diurnal changes to be published soon by R. C. Gentry indicate that the line of zero change that lies along our east coast for the 0300–1500 changes will be shifted eastward for 0000–1200 GMT times.

3. EXTRAPOLATION OF PRESSURE HEIGHTS

Differential analysis is not new, for it has been used for more than a decade [4, 5, 6]. The material that is new, however, is the climatology upon which the tropical analyst must base his differential analysis; information which previously resided only in the minds of a few experienced tropical analysts.

The suggested use of these mean maps is to add onto the 1000 mb. heights the appropriate thickness at a network of grid points, plus or minus local adjustments to those means; i. e., local anomalies where they can be estimated. The validity of vertical extrapolation is clear when we consider the tropical atmosphere over oceans. The horizontal temperature gradient is normally small so if the atmosphere were entirely barotropic the day-to-day height variation of upper pressure surfaces would be controlled to a high degree by the sea level pressure. Most of the lower tropical atmosphere is in fact nearly barotropic for the 700-mb. and 500-mb. heights are highly correlated with the 1000-mb. height. It follows that a straightforward addition of normal thicknesses to a *good* 1000-mb. analysis wherever there are no upper-air data, would produce an upper-air map that is superior to an analysis made solely from upper-air observations. Such a procedure is not recommended, however, for it neglects significant features that can be added by a skillful analyst whose task it is to determine the pattern of anomalies. It was a search for anomaly indicators that comprised a large part of this study.

Extrapolation for purposes of synoptic description in the Tropics is more difficult than at higher latitudes for two reasons. First, because the gradients are small, upper-air analysis must delineate relatively small changes in time and space. Second, the semidiurnal pressure wave and the diurnal temperature wave are large and in practice these real complications are compounded by communications, instrumental, and human errors. The effect of large day-to-night changes is to decrease the value of normals based on combined 0300–1500 GMT soundings. The first requirement, then, is separate normals. A second requirement—detection of errors—can be met by the careful application of time continuity. Many errors can be eliminated by maintaining a surveillance of the reported changes in light of the changes to be expected in a tropical atmosphere.

4. INADEQUATE ANOMALY INDICATORS

Many avenues were explored in an effort to find some practical means of estimating thickness anomalies both from the surface parameters and from circulation features. Since other investigators may want to avoid covering the same ground, those avenues which did not yield usable results will be mentioned, but without documentation. It should be borne in mind that all the following pertains to the tropical atmosphere below 500 mb. in the American Tropics during the hurricane season.

Airmass considerations, so important at higher latitudes [4] were of small value because, except at the boundaries of our region, e. g., north of 20° N. and in the Gulf of Mexico, almost no detectable airmass differences exist. Even when fronts are found at the surface, the cool air is quite shallow so that frontal analysis is seldom any clue to thickness anomaly. This does not preclude the use of frontal analysis in the rare occasions when it is clear that a deep cool airmass has invaded the Tropics.

Weather and cloud distribution is frequently used in tropical analysis as an indication of stability and subsidence warming or of a moist adiabatic lapse rate. Only insignificant correlations were found between thickness and weather distribution, but this is understandable for the following reasons. Perhaps the most important is that weather distribution analysis is strongly influenced by the complete and regular reports from island stations where local terrain effects produce weather not representative of large areas. This particular phase of the study cannot be considered complete until it is repeated with weather distribution charts based on ship reports, but a similar study for higher latitudes has not been encouraging [7]. In oceanic Highs there are compensating effects which will always produce a great variety of anomalies of *both signs* with fair weather. On one hand, the atmosphere has subsided various unknown amounts so that the degree of warming is uncertain, but at the same time the layer between, say 1000 mb. and 700 mb. is at a greater elevation, thus is cooled as the 1000-mb. surface rises because the temperature at sea surface and the lapse rate from surface to 1000 mb. remain nearly constant.

Surface temperature and pressure are very poor indicators of thickness anomaly. Insofar as temperature is concerned, the lowest values are usually associated with showers so that any given report may show the temperature of precipitation-cooled air that is unrepresentative. The effect of pressure is indeterminate as well, in part for the reason just mentioned in connection with the high pressure cells.

Circulation features such as troughs and ridges or curvature of the flow are associated with only a small part of the anomalies and, in general, do not assist in estimating their magnitude. In the absence of any other information, a safe rule is to assign a small negative anomaly to the immediate region of a moving trough in the easterlies. Ridges do not appear to carry with them significant anomalies. Furthermore, less than half of all large anomalies are associated with circulation features detectable from the conventional analysis so that if one assigned anomalies strictly on the basis of circulation, he would indicate zero anomaly in about 60 percent of the cases where large anomalies actually exist and small anomalies of the correct sign would be estimated correctly no better than expected by chance.

Horizontal interpolation has been used successfully in oceanic analysis at higher latitudes [7] and these considerations are of some value in the Tropics, but not to the same degree. The manner in which this is applied is discussed below.

Estimating 700-mb. or 500-mb. temperatures as a step in estimating the various thicknesses cannot be done any more accurately than estimating the anomaly directly. If reliable aircraft or short-run raobs are available, however, good estimates of ΔH_3 can be obtained and this is discussed below.

Estimating ΔH_2 anomalies from those that exist in ΔH_1 is a valid procedure if there are more data for the 700-mb. analysis than for the 500-mb. analysis. Where no additional data exist at 700 mb., however, no accrual of accuracy can result because no clues to ΔH_2 anomalies were found on the 700-mb. analysis that were not also evident at the surface. It is evident from the larger standard deviations of ΔH_3 that the 500-mb. analysis will always be more uncertain than the 700-mb. analysis. (See discussion of vertical distribution of anomalies in section 5.)

5. STATISTICAL ANALYSIS AIDS

The only systems that carry with them definite anomalies are strong troughs, tropical storms, and hurricanes. Obviously, in a typical situation, this leaves something over 90 percent of the tropical region with no dependable clues to thickness anomalies insofar as circulation or weather indications are concerned. The analyst must therefore turn to time continuity and horizontal extrapolation from regions of upper-air data. Statistical evidence upon which to base the latter is not entirely satisfactory because the results are based on anomalies at widely separated stations. Time continuity statistics, since they depend upon local changes only, are much more dependable and are recommended as the main tool. Since time continuity is presently the best analysis aid, it is vital that careful re-analysis of upper-air and surface maps be made routinely as subsequent data [3] become available, for it is clear that if maps during the past 24 hours are not revised to obtain the most accurate pattern possible there is very little point to time extrapolation.

[3] "Subsequent data" includes weather events right up to the re-analysis time as well as late ship and upper-air reports, both on and off map time.

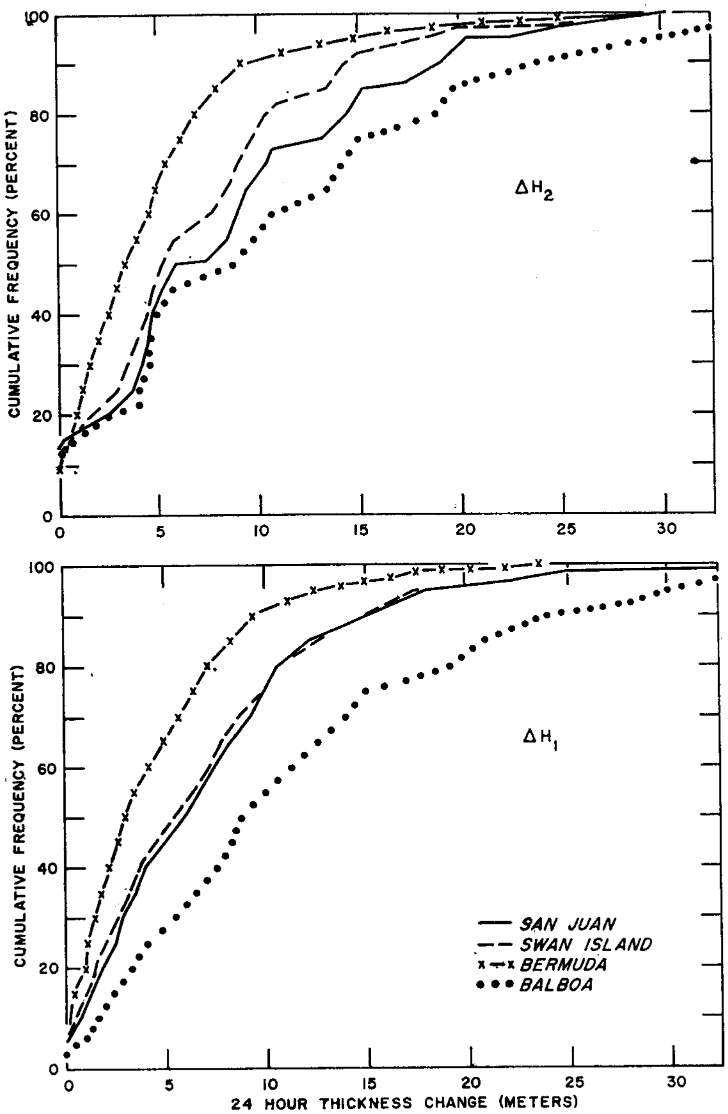


FIGURE 1.—Cumulative frequency of 24-hour thickness changes for the layers 1000–700 mb. (ΔH_1) and 700–500 mb. (ΔH_2), July through November.

Time continuity of thickness anomalies is a valuable analysis aid if it is applied with the help of pertinent climatology of the area. Following are some of the statistics that the analyst must incorporate into every map.

Figure 1 shows cumulative frequencies of 24-hour thickness changes for ΔH_1 and ΔH_2, showing that over most of the American Tropics 90 percent of the 24-hour changes are 15 meters or less in the lower stratum and 90 percent are 20 meters or less in the upper layer. During this season some of the larger changes are produced by traveling waves that pass a given point every 4 to 5 days (see San Juan, fig. 2) so that on the average, perhaps 5 to 10 percent of the changes are produced by these waves. Some of the wave-induced changes in ΔH_1 must be greater than 15 meters, so it follows that a large part of the area not under the immediate influence of a wave must show changes less than 15 meters; on a typical map this represents most of the analysis area. This statistic therefore represents a definite restraint the analyst is obliged to impose. For example, in regions where there is no reason to suspect a disturbance, changes much greater than 15 meters must be viewed with suspicion and every effort made to revise the map to eliminate the large changes.

The tendency for the thickness (or anomaly) to be similar on two successive days is also shown by autocorrelation (lag) coefficients.[4] Figure 2 shows this statistic for ΔH_1 for five stations. The 4- to 5-day periodicity prominent at Trinidad and San Juan is understandably absent at Bermuda where the circulation is dominated by an anticyclone, but the absence of any lag correlation at the Canal Zone is more difficult to interpret. No doubt circulation changes bring intermittent invasions of continental air from South America or cool air from the eastern Pacific. Some of the erratic changes (thus the low lag correlation) must be due to low quality soundings because few of the larger anomalies appear on two successive days, but a certain amount of this effect must be real because at Swan Island the 24-hour lag coefficient is also low. Whatever the cause, it is apparent that 24-hour time continuity is of little value in this area. Even here some analysis stability can be obtained by using longer-term tendencies. Large areas frequently are above or below normal for several successive weeks, so a running mean of thickness anomaly will often provide an indication of the anomaly that is better than using the normal value (zero anomaly). This is illustrated by figure 3. Notice the period during which the running mean is completely above or below normal.

The statistics discussed above, being averages, characterized the central tendency and suppress the extremes. On almost every map the analyst finds areas of large anomalies that are not documented by data one day later and a useful statistic is the amount these large anomalies are likely to decrease in 24 hours at that locality. Figure 4 shows the 24-hour change of anomaly toward zero as a function of the anomaly magnitude. When the analyst is faced with the problem of estimating a thickness anomaly 24 hours after a large, reliable value appeared, in the absence of other information the best estimate may be based on the graph for the appropriate area. Because these graphs were constructed from all large anomalies during the period involved, a certain proportion are changes due to traveling disturbances. Therefore, the 24-hour changes indicated do not apply strictly to either wave or to non-wave anomalies, but the influence of synoptic systems is believed small. It must be borne in mind that this statistic refers to the anomaly change at a fixed point and that large anomalies associated with traveling disturbances frequently do not decrease in any given 24-hour period, so the 24-hour decrease is a measure of the advective decrease.

Horizontal extrapolation is useful in a qualitative manner only, for thicknesses are influenced strongly by vertical motions not detectable from routine analysis. Further-

[4] These were computed for full days only and the coefficient for 1-day, 2-day, etc. connected with a smooth curve. This fact, along with a different period of record, accounts for a 4-day periodicity at Trinidad but a 5-day period at San Juan.

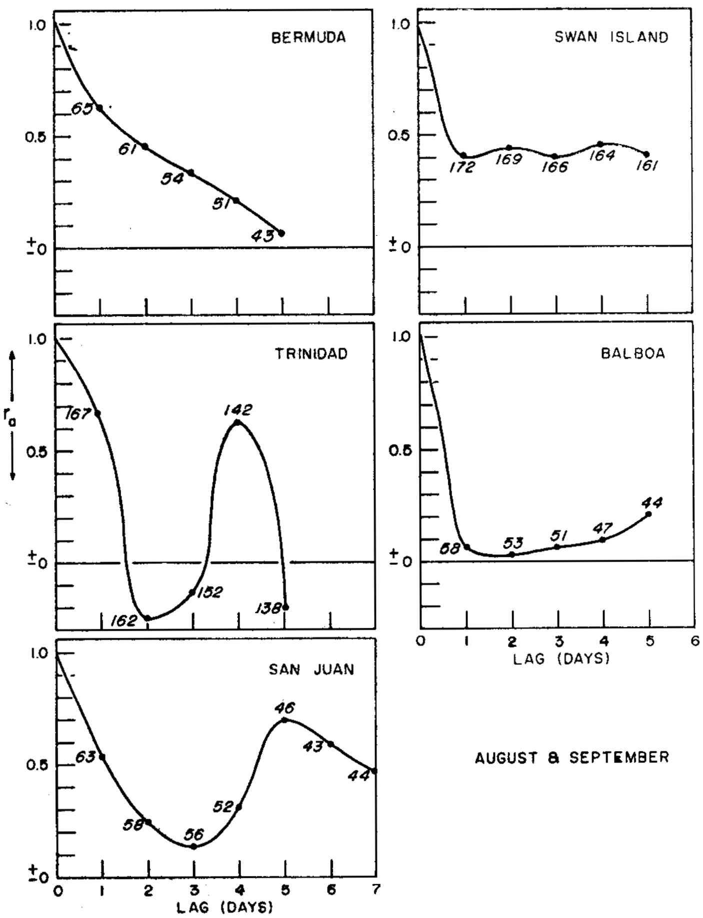


FIGURE 2.—Lag correlation coefficients for layer 1000–700 mb. for months of August and September. Number of cases is shown at each point.

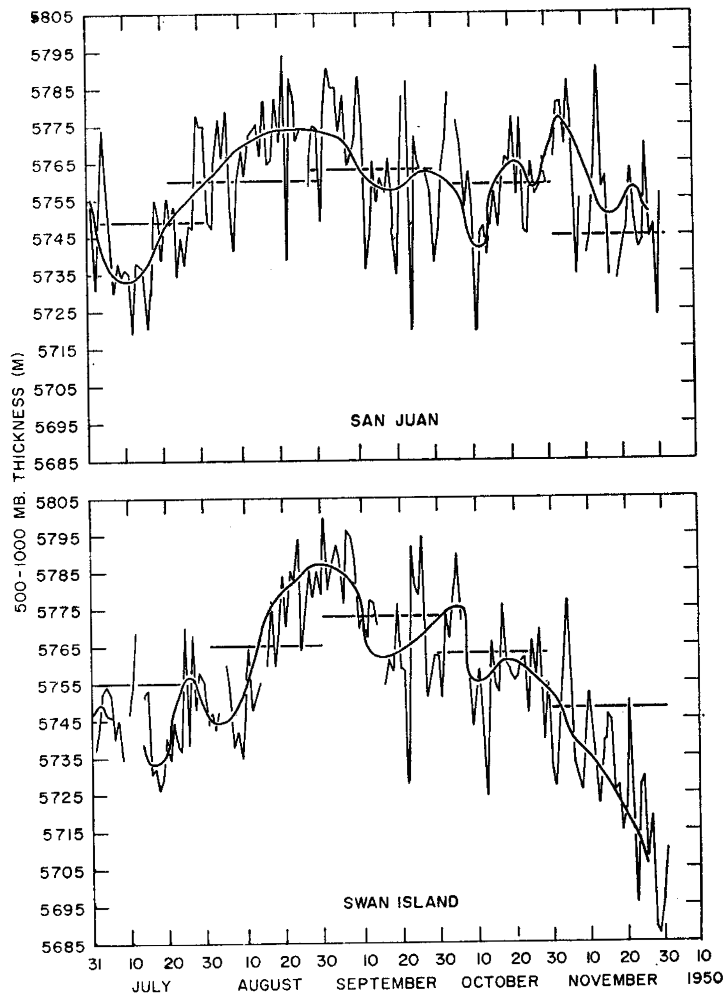


FIGURE 3.—Comparison of running 5-day means and 0300 GMT values with corresponding monthly means of layer 1000–500 mb. (ΔH_3), hurricane season 1950.

more, the areas of anomaly associated with synoptic systems are quite small. For example, *waves in the easterlies* frequently have negative anomalies of 10 to 20 meters in ΔH_1 and in ΔH_2 about 100 n.mi. up- and downstream from the trough line. (Troughs in the westerlies are usually colder and have larger anomaly areas.)

Tropical storms usually have associated with them negative anomalies greater than 15 meters since they are associated with strong troughs, but the anomaly areas rarely extend over the entire region of cyclonically curved contours.

The mature hurricane always carries a positive anomaly in ΔH_2 and ΔH_3, but the area is typically perhaps less than 3° of latitude from the center [8]. On the other hand, the area of positive anomaly in the 700–1000-mb. layer is so small that it is not apparent from data unless the storm is very near an upper-air station, and even 50 to 100 miles from the eye negative ΔH_1 anomalies are observed.[5]

Areal distribution of anomalies apparently is homogeneous enough to permit qualitative extrapolation. Inspection of several months of anomaly charts (plotted from station data—not analyses) showed that a single zero line frequently appears in the tropical region, or at most, a central zone of one sign is flanked on either side by areas of the opposite sign. This is analogous to an airmass characteristic with large continuous areas slightly cooler than normal or slightly above normal. Although the boundaries of these zones are not marked by fronts or shearlines, this feature permits one to extrapolate at least the sign of the anomaly over relatively large areas.

Vertical distribution of anomalies also shows some regularity, but the relation of ΔH_1 to ΔH_2 changes from place to place, as one might expect in view of the different circulation regimes. Figure 5 shows linear correlation coefficients between the strata for each of the five hurricane months. It is significant that the correlations are lowest through the central portion of the analysis area, just where the waves attain their greatest amplitude, reflecting perhaps the fact that in the non-disturbed areas the temperatures fluctuate as a single "airmass", while in the waves variable vertical motions affect the layers in a more complex manner. The analyst therefore should estimate anomalies to be quite similar in both

[5] This is evident from a mean hurricane sounding [9] which is typical of radial distances of 1° to 2.5° of latitude, when it is compared to the mean tropical sounding for the same area and months [10] as follows:
Anomalies: $\Delta H_1 = -3$m.; $\Delta H_2 = +21$m.; $\Delta H_3 = +18$m.

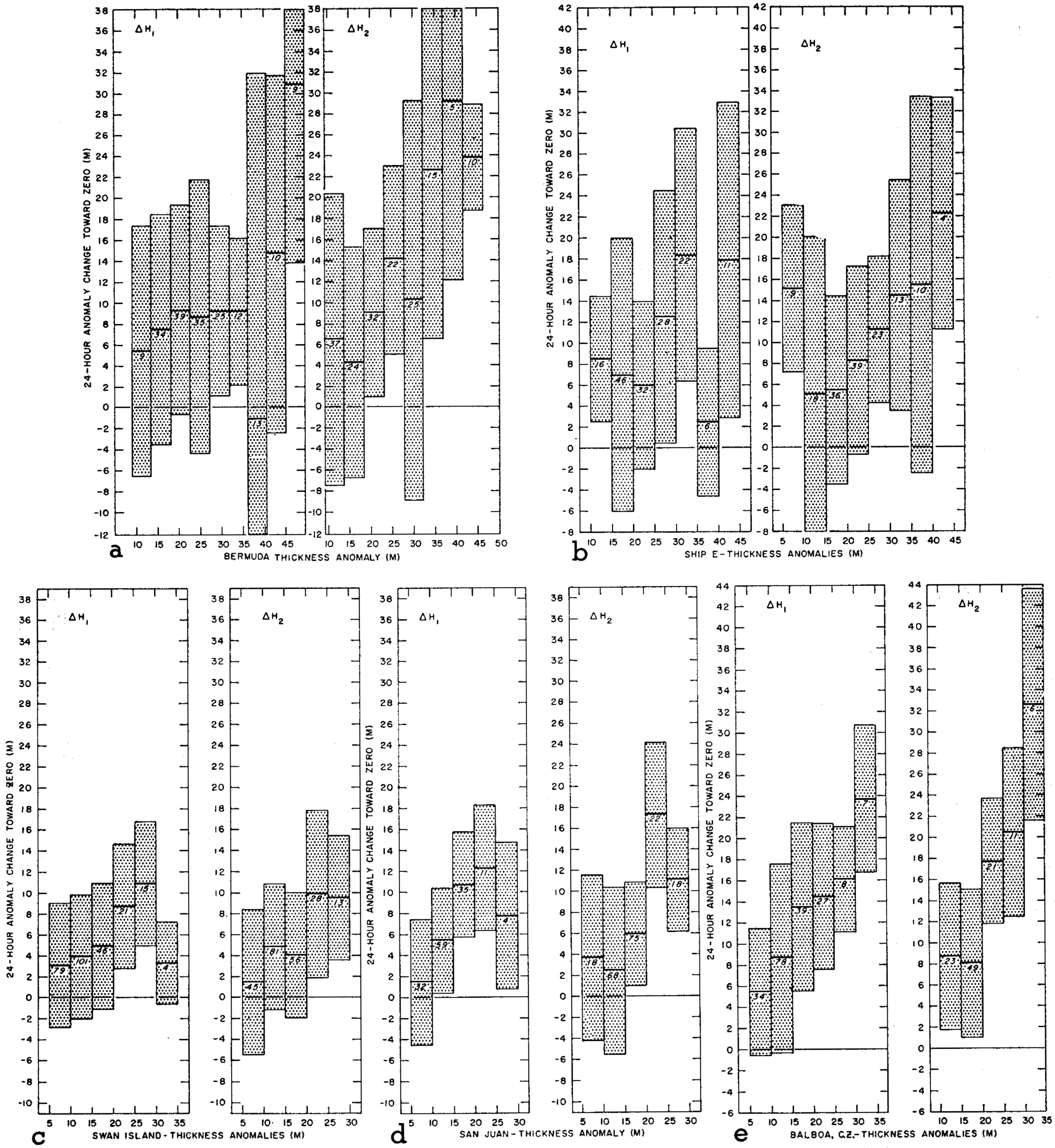
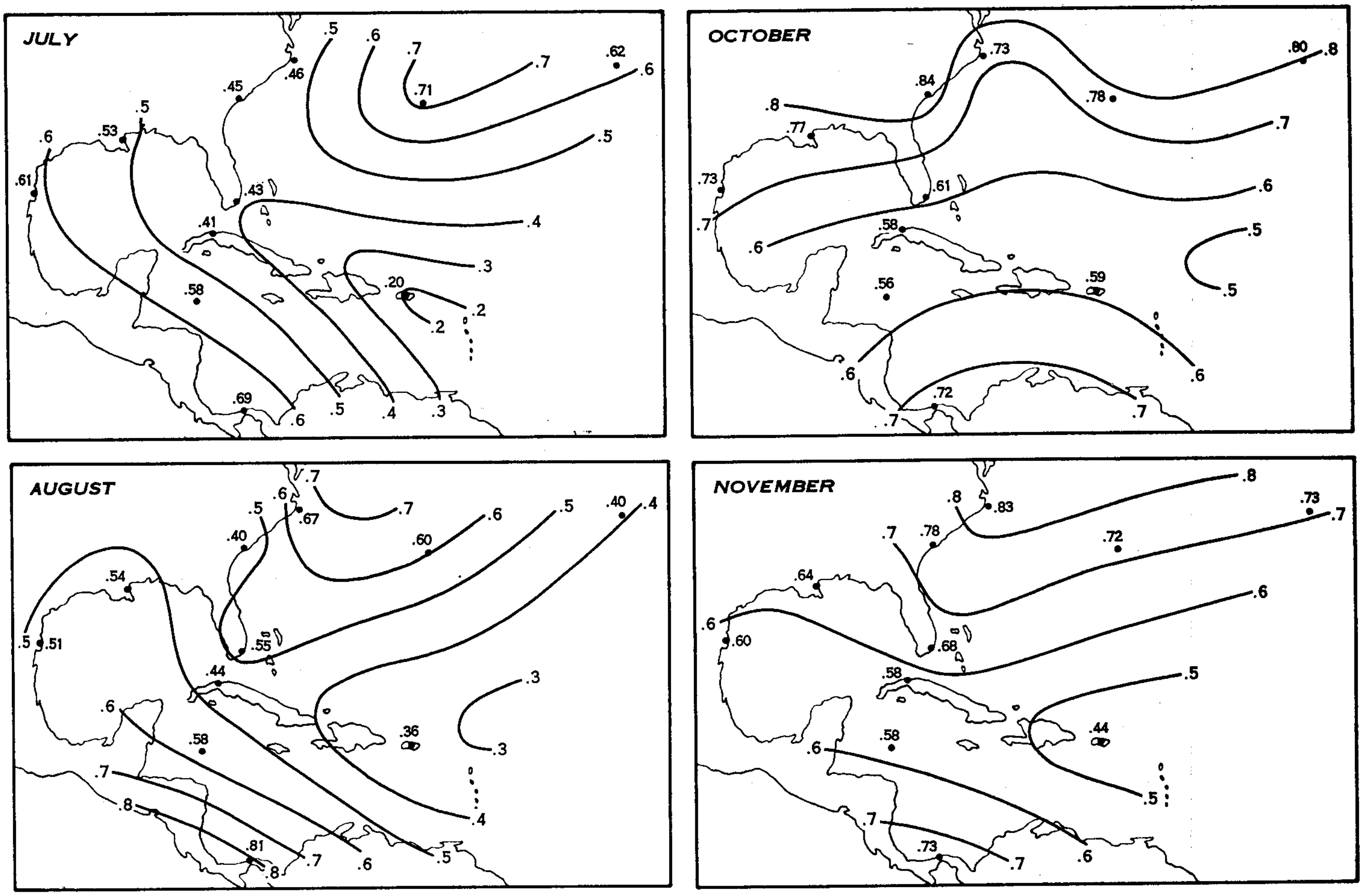


FIGURE 4.—Twenty-four-hour "return to normal" of thickness as a function of anomaly magnitude in the layers 1000–700 mb. (ΔH_1) and 700–500 mb. (ΔH_2), July through November. Horizontal lines indicate values of mean 24-hour change and size of class intervals used, with number of cases in each class shown. Shaded bar indicates range of the probable error.



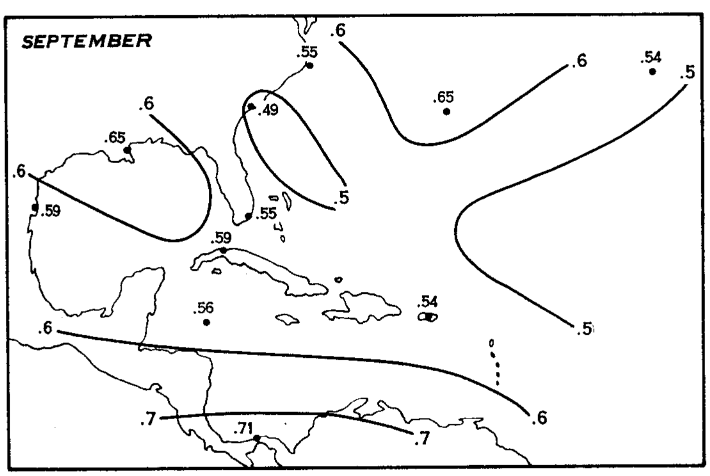


FIGURE 5.—Linear correlation coefficients between layers 1000–700 mb. and 700–500 mb. at 0300 GMT for the hurricane season.

layers in the northern and southern zones, but should not attempt to place this restriction on the patterns of the central part, especially in disturbed areas.

Temperature at 700 mb. is correlated with thickness, thus with anomaly in the various layers discussed here. It is of interest to notice, however, that it is not a simple relation, such for example that a degree of temperature increase at 700 mb. corresponds to a degree of increase in the mean virtual temperature in the layer 1000–500 mb., as illustrated by the following:

The hydrostatic equation can be written

$$\Delta Z = \frac{R\overline{T}}{g} \ln (1000/500) \text{ or } \Delta H_3 = 20.3\overline{T} \tag{1}$$

where $\overline{T}$ is the mean virtual temperature in degrees K. and ΔH_3 is in meters.

Now, if it were true that a good estimate of $\overline{T}$ could be obtained from the 700-mb. temperature, for example,

$$\overline{T} = T_7 + k \tag{2}$$

where $\overline{T}_7$ is the 700-mb. temperature and k is a constant depending upon the average stability and moisture content of the layer involved, then

$$\Delta H_3 = 20.3\ k + 20.3\ T_7 \tag{3}$$

The linear regression lines of T_7 on ΔH_3 for Balboa, C. Z. and for Ship E have slopes of 15 and 13, respectively, as compared to 20.3 of equation (3). Therefore the relation between mean virtual temperature and the 700-mb. temperature expressed in equation (2) is not sufficiently good for this purpose; so it is necessary to use empirically derived regression lines from point to point

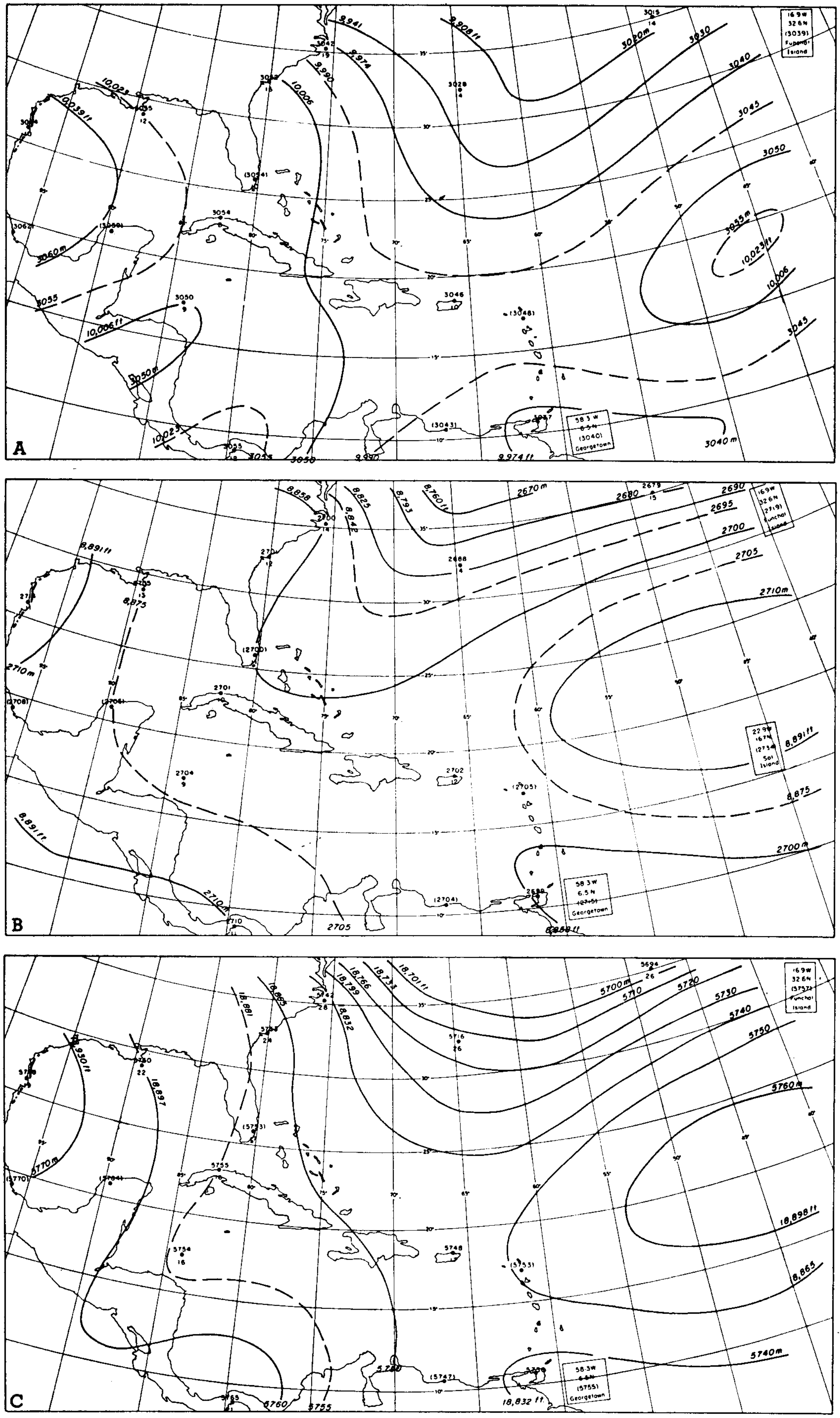


FIGURE 6.—Mean thickness and standard deviation of thickness (meters) for 0300 GMT, for July. (A) 1000–700 mb. (ΔH_1), (B) 700–500 mb. (ΔH_2), and (C) 1000–500 mb. (ΔH_3).

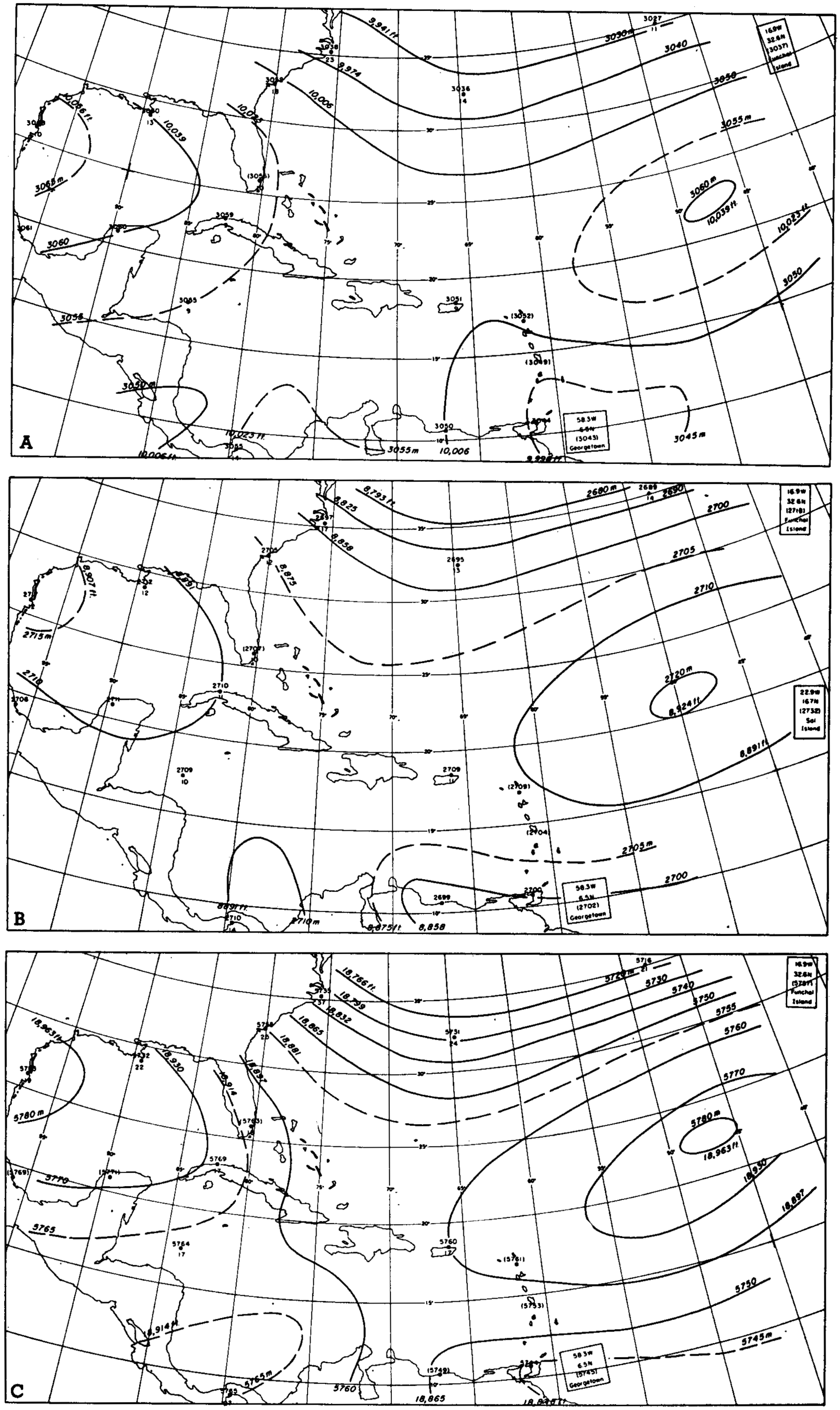


FIGURE 7.—Mean thickness and standard deviation of thickness (meters) for 0300 GMT, for August. (A) 1000–700 mb. (ΔH_1), (B) 700–500 mb. (ΔH_2), and (C) 1000–500 mb. (ΔH_3).

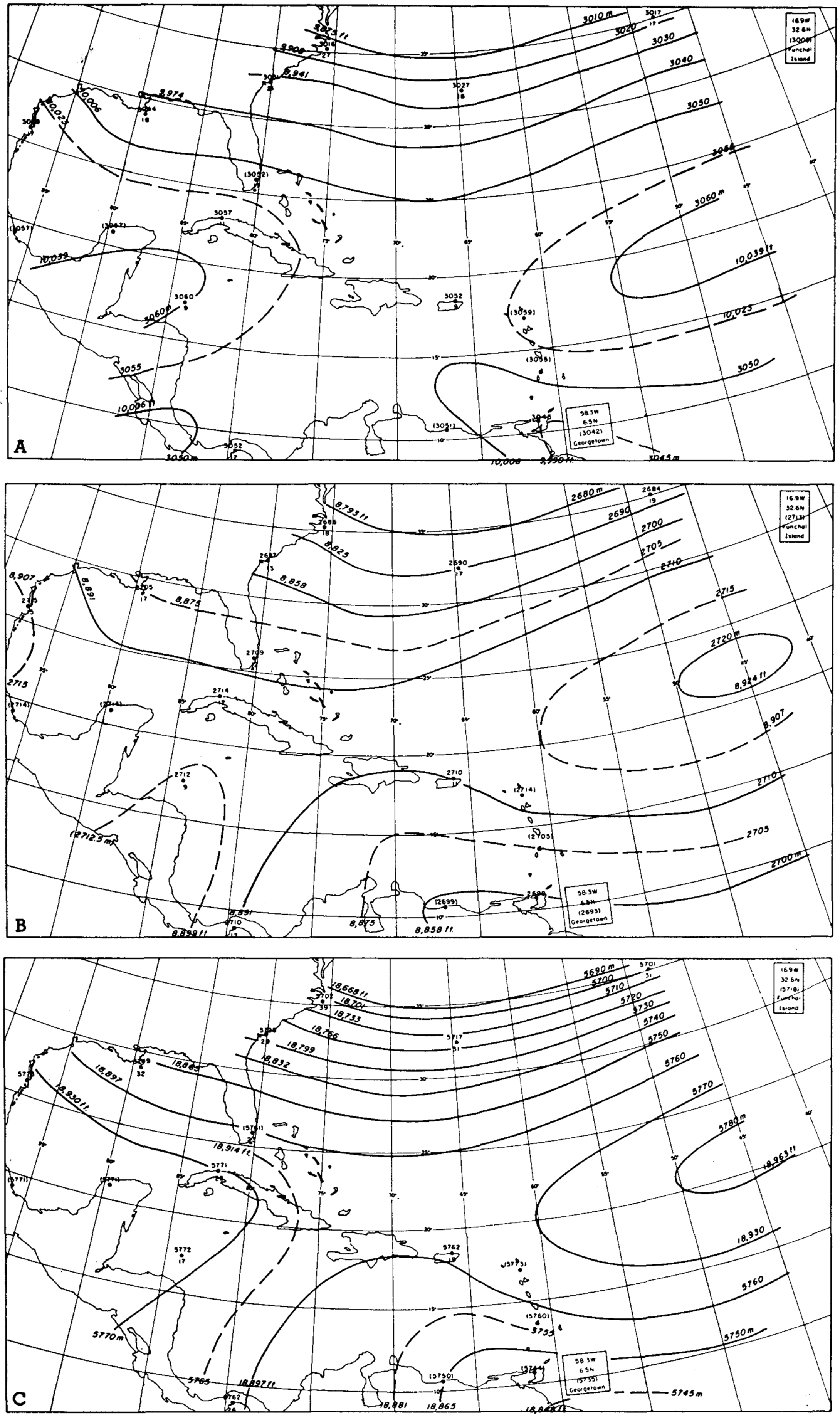


FIGURE 8.—Mean thickness and standard deviation of thickness (meters) for 0300 GMT for September. (A) 1000–700 mb. (ΔH_1), (B) 700–500 mb. (ΔH_2), and (C) 1000–500 mb. (ΔH_3).

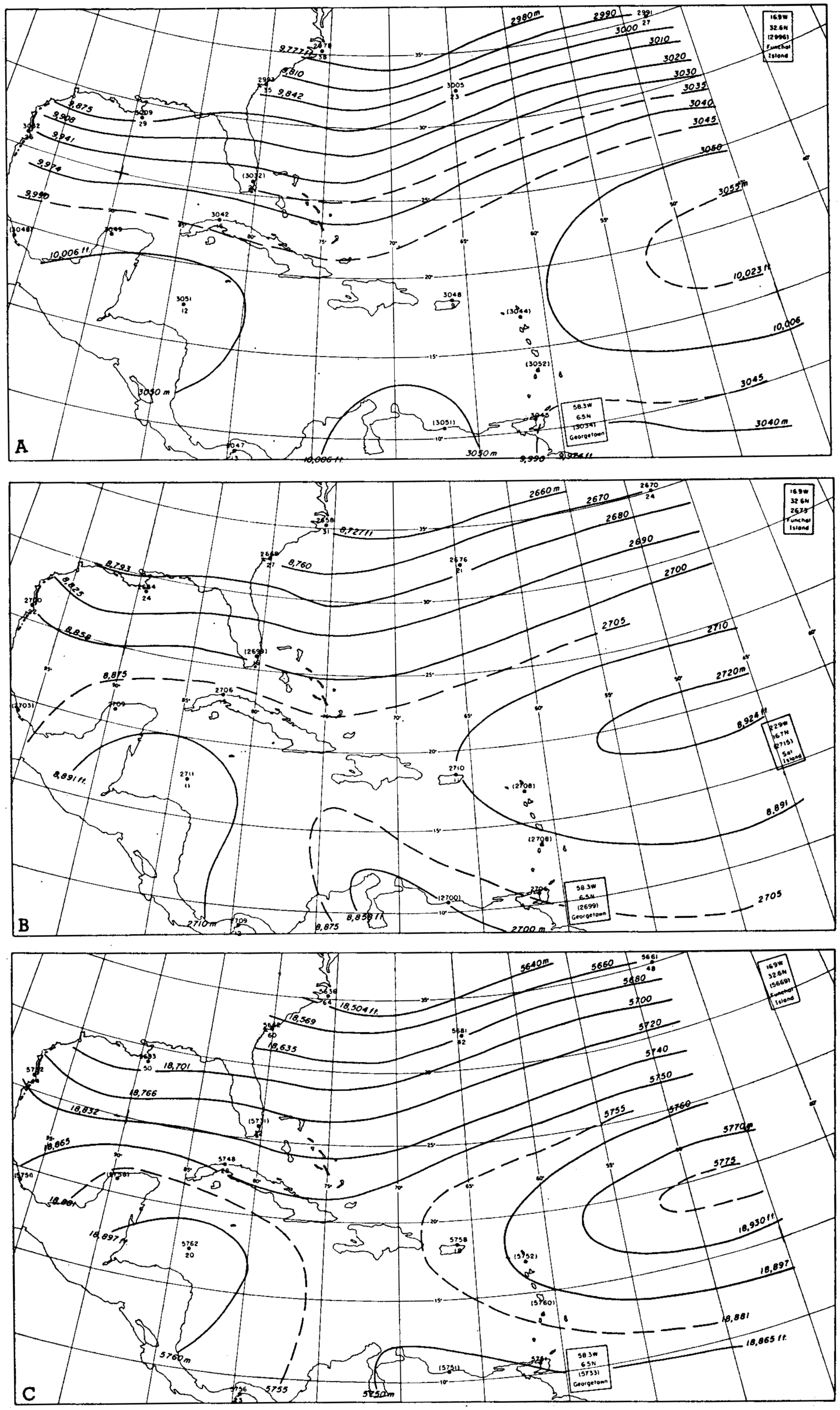


FIGURE 9.—Mean thickness and standard deviation of thickness (meters) for 0300 GMT for October. (A) 1000–700 mb. (ΔH_1), (B) 700–500 mb. (ΔH_2), and (C) 1000–500 mb. (ΔH_3).

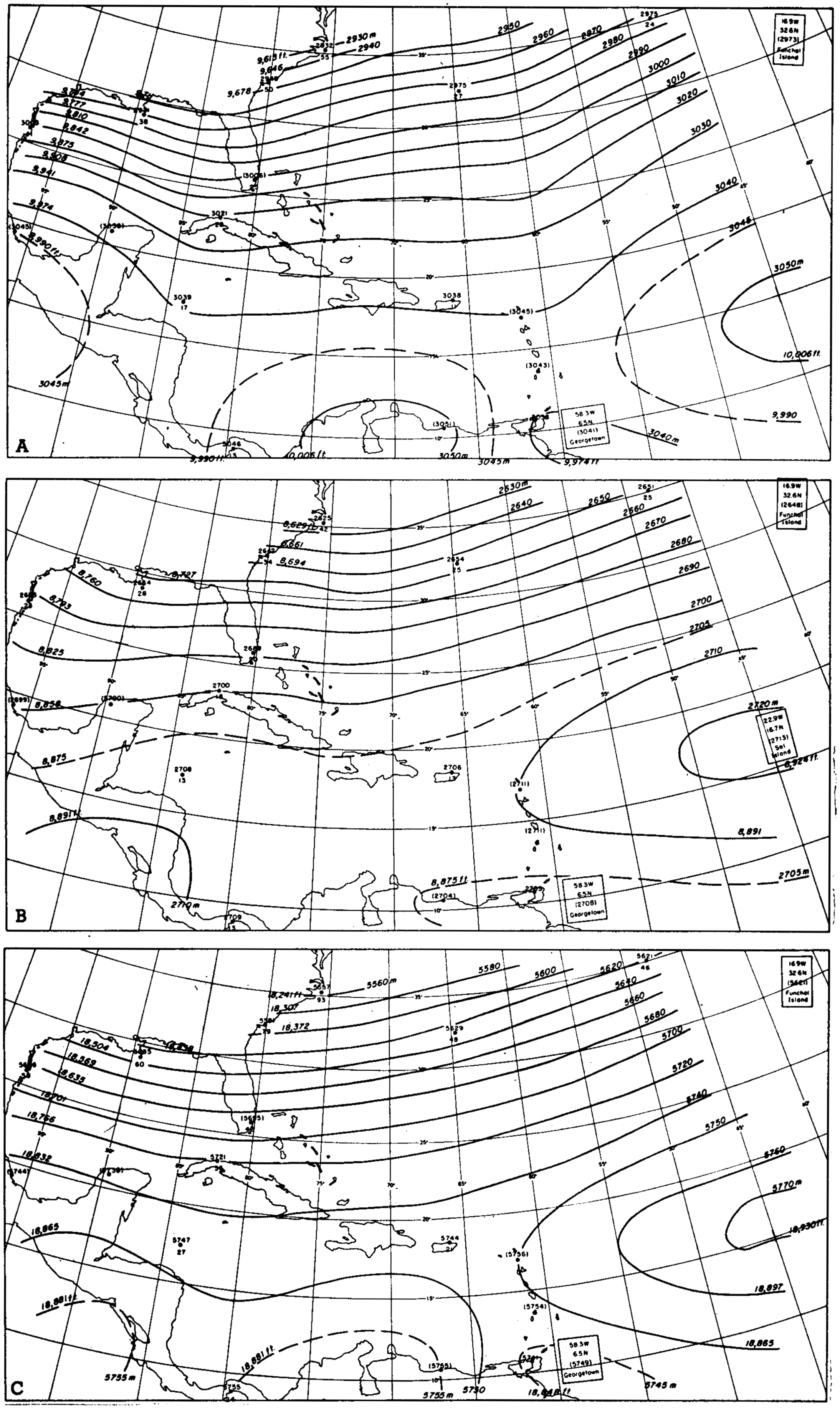


FIGURE 10.—Mean thickness and standard deviation of thickness (meters) for 0300 GMT for November. (A) 1000–700 mb. (ΔH_1), (B) 700–500 mb. (ΔH_2), and (C) 1000–500 mb. (ΔH_3).

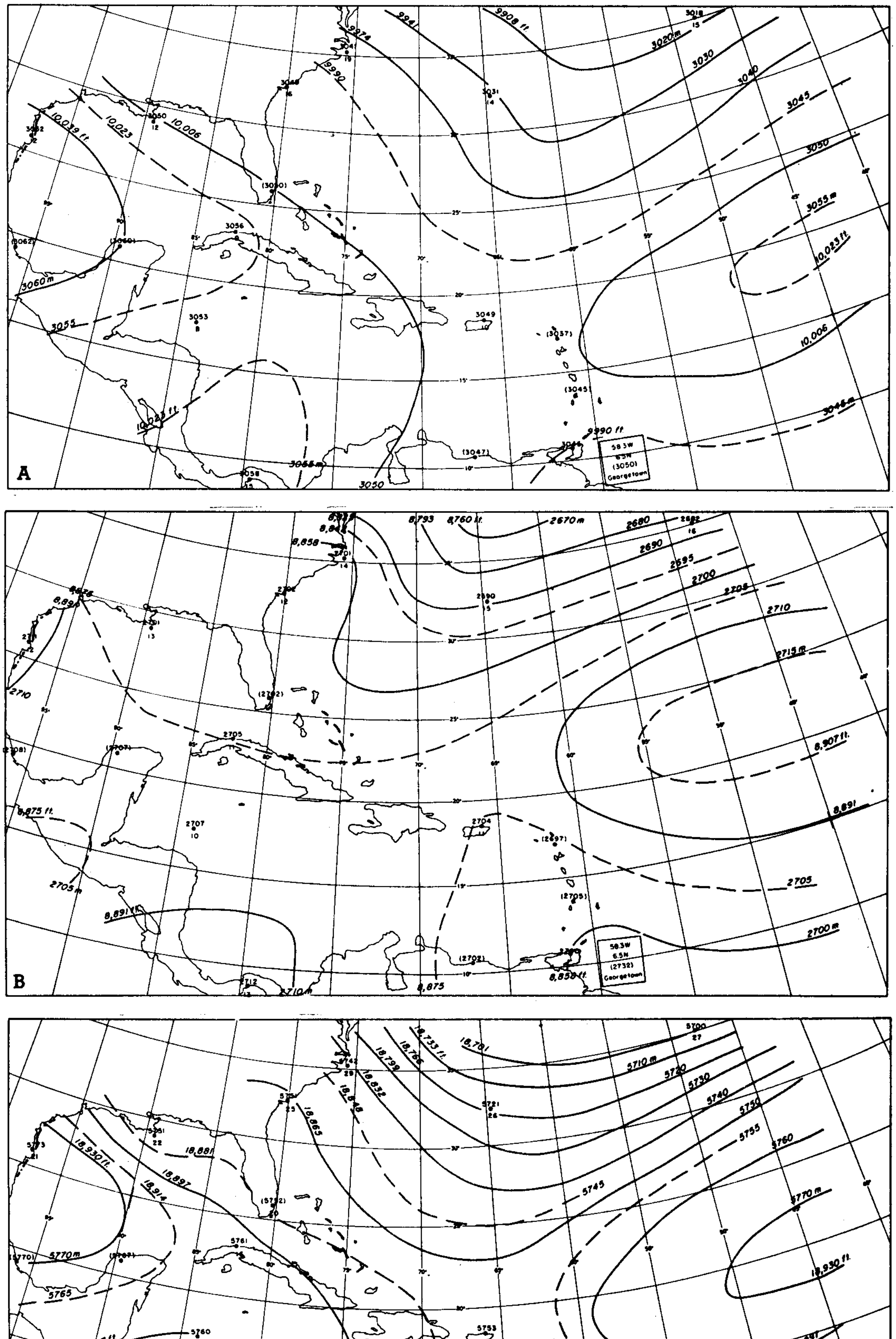


FIGURE 11.—Mean thickness and standard deviation of thickness (meters) for 1500 GMT for July. (A) 1000–700 mb. (ΔH_1), (B) 700–500 mb. (ΔH_2), and (C) 1000–500 mb. (ΔH_3).

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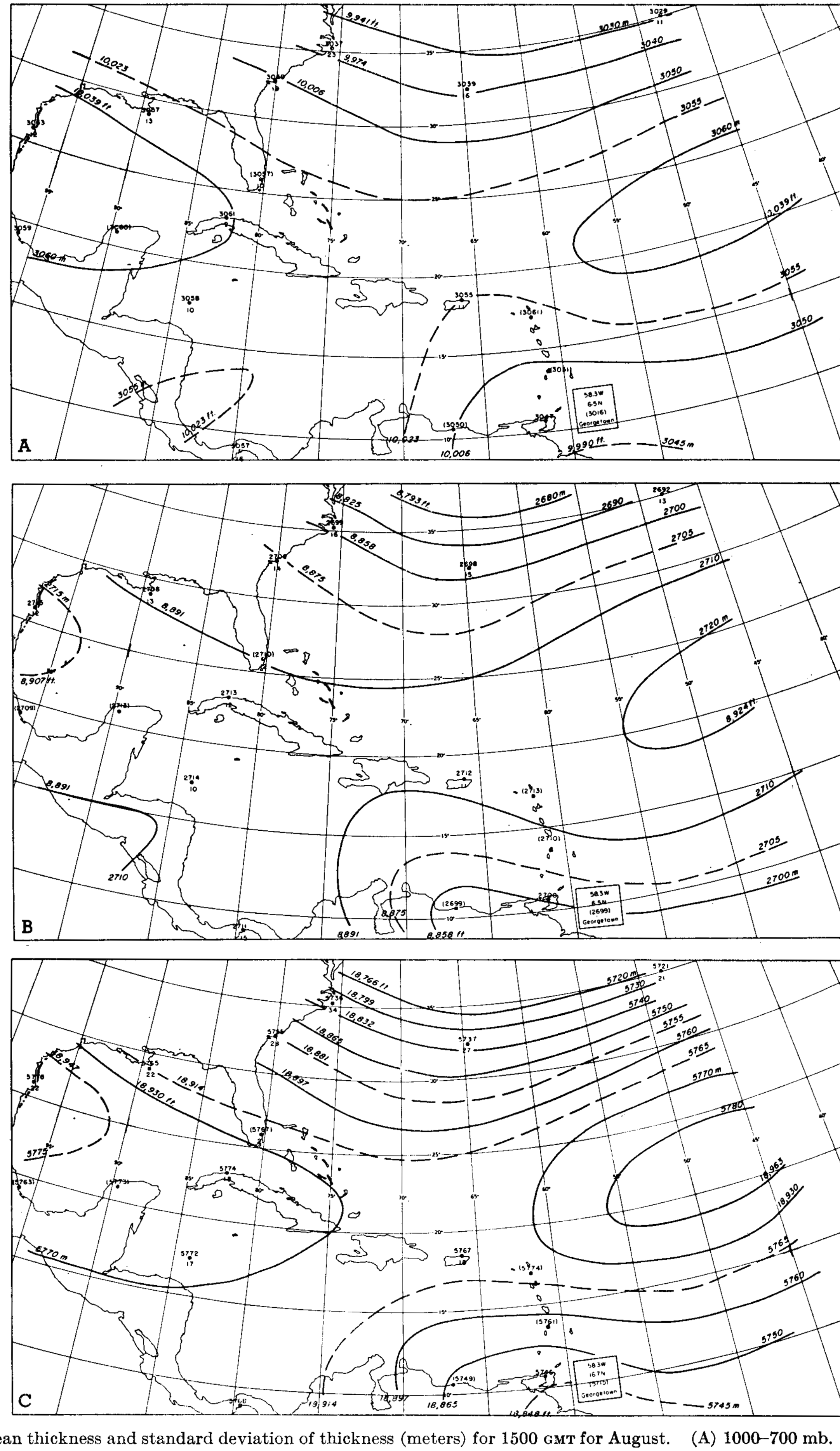

FIGURE 12.—Mean thickness and standard deviation of thickness (meters) for 1500 GMT for August. (A) 1000–700 mb. (ΔH_1), (B) 700–500 mb. (ΔH_2), and (C) 1000–500 mb. (ΔH_3).

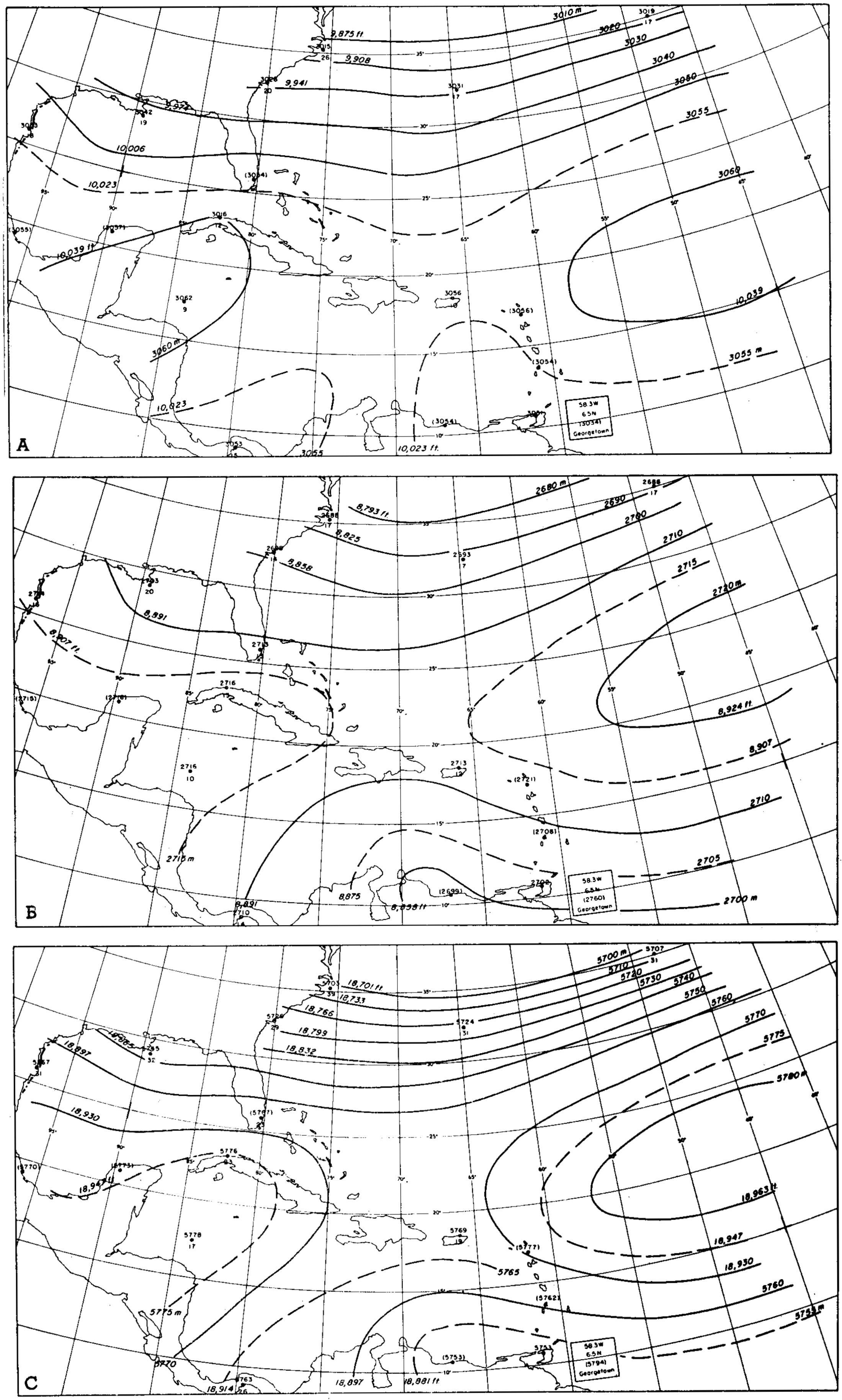

FIGURE 13.—Mean thickness and standard deviation of thickness (meters) for 1500 GMT for September. (A) 1000–700 mb. (ΔH_1), (B) 700–500 mb. (ΔH_2), and (C) 1000–500 mb. (ΔH_3).

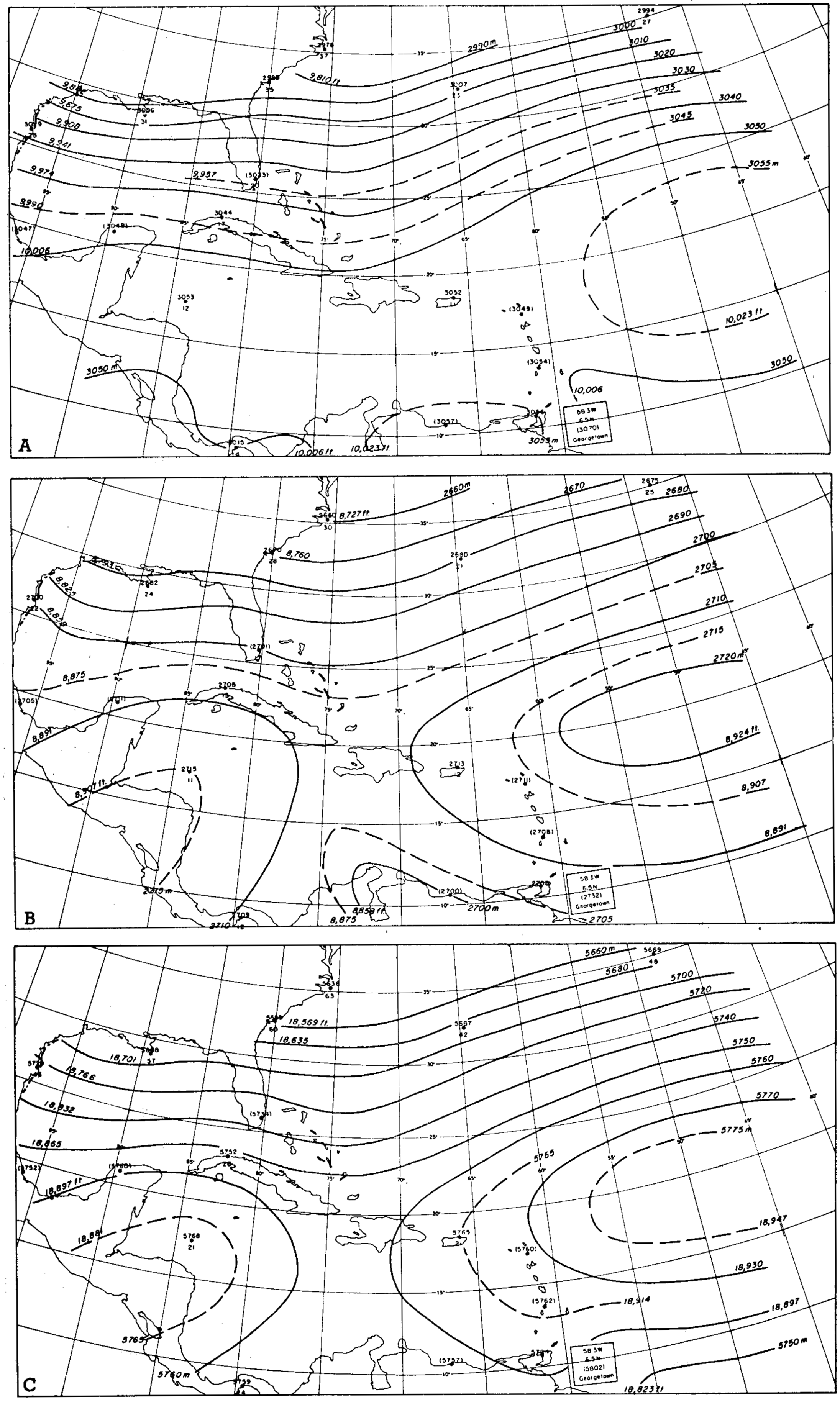

FIGURE 14.—Mean thickness and standard deviation of thickness (meters) for 1500 GMT for October. (A) 1000–700 mb. (ΔH_1), (B) 700–500 mb. (ΔH_2), and (C) 1000–500 mb. (ΔH_3).

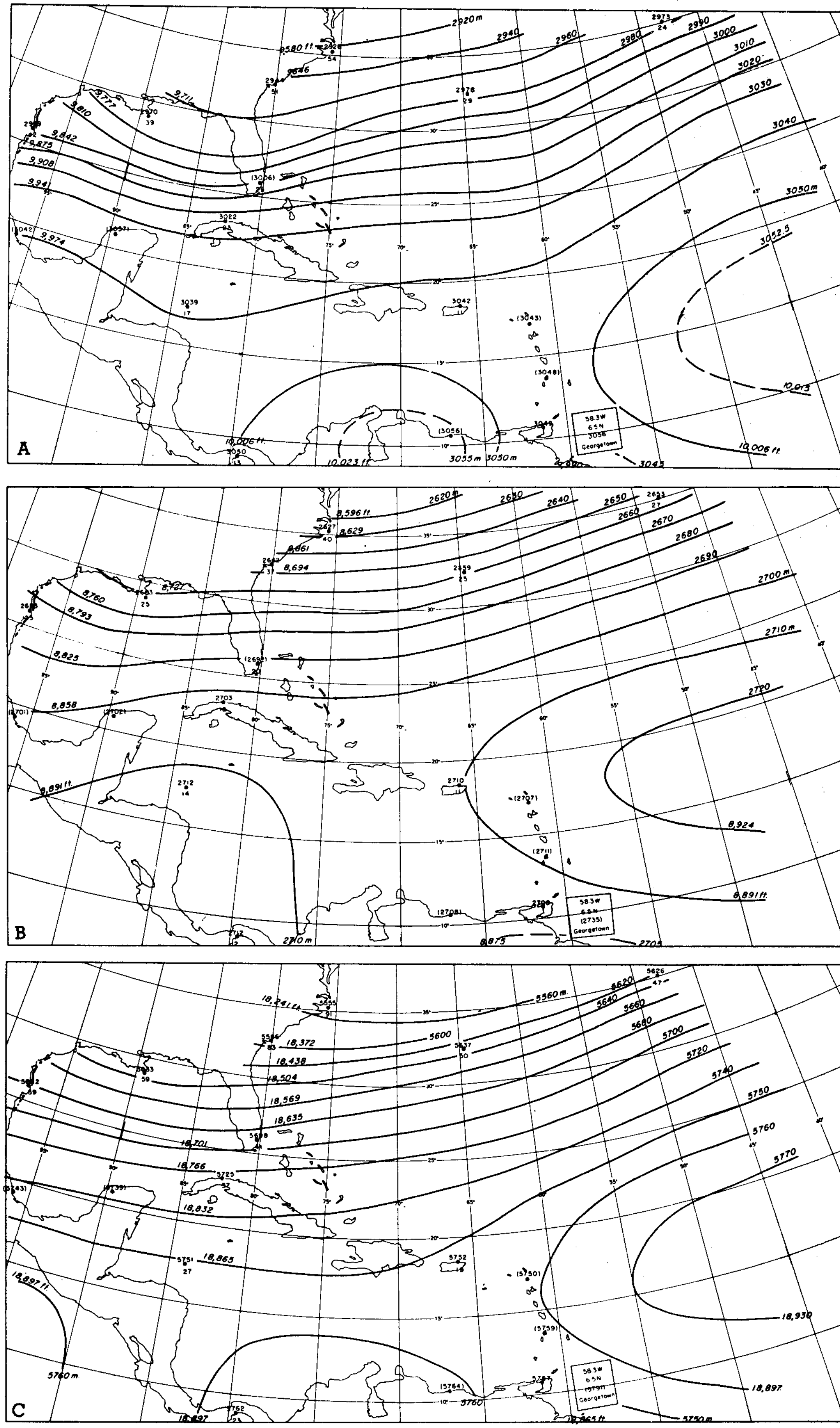

Figure 15.—Mean thickness and standard deviation of thickness (meters) for 1500 GMT for November. (A) 1000–700 mb. (ΔH_1), (B) 700–500 mb. (ΔH_2), and (C) 1000–500 mb. (ΔH_3).

over the analysis region, if 700-mb. temperatures are to be used in this manner.

6. DISCUSSION OF ANALYSIS PROCEDURES

Since analysis must depend so critically upon time continuity, a constant re-analysis of every map must be a routine procedure and every report, both on- and off-time, must be plotted and considered. For example, off-time ship reports might indicate an analysis error that was made on the previous 0000 GMT map. Before the 1200 GMT map is analyzed the previous map must be corrected and this in turn will change the thickness in that region, and perhaps require an adjustment of the upper-air map.

The contour fields are frequently so flat that graphical subtraction is unsatisfactory; rather, subtraction of heights at a net of grid points, say at 5° of latitude and longitude, is necessary. Furthermore, anomalies must be examined in the light of time continuity and adjustments made where the magnitude of their changes exceeds reasonable values. It will be a rare analysis that does not require some adjustment after the thickness changes have been examined, so it is important to allow for this in the analysis routine.

Important extremes of thickness that develop over data-free areas will of course go undetected by this or any other procedure currently available, but this does not mean the analyst cannot detect synoptic disturbances. Areas of greater than average cloudiness and precipitation are almost always evidence of a wave-like disturbance or a shear line and the low-cloud directions can indicate the most likely flow configuration, so the procedures outlined will produce a wave in the upper-air field of motion, even though the anomaly is unknown.

The point of the argument presented here is that contours cannot be drawn in a satisfactory manner by analyzing only the radiosonde-rawin reports. This is due to the fact that with a sparse upper-air network and a flat pressure field, little meteorological restraint is imposed on the shape of contours over large areas, and a pattern may appear "reasonable" even though it implies a temperature distribution that is completely unreasonable!

On the other hand a vast improvement can be realized by applying the principles of differential analysis because variation in pressure height is the sum of variation in surface pressure and variation in mean temperature, and a large part of this sum is always contributed by the surface pressure field. Fortunately the latter is easy to analyze because there are relatively a great number of reliable reports and, in addition, the thickness field is moderately conservative for the great majority of changes are small and the largest anomalies are associated with disturbances that are advected at a rate frequently deducible from surface analysis.

The methods discussed here are of course subjective, despite the appeal to synoptic climatology. The writer feels that subjective methods cannot be surpassed in this area under the present standards of instrumental accuracy and status of the data network. For that reason there is no substitute for an experienced analyst who can fit the observations into the framework of synoptic climatology to produce the best estimate of the contour field.

It is not the purpose of this paper to suggest any particular analysis routine, but it is clear that where a high-quality analysis of the American Tropics is required, differential analysis, based on considerations of the type presented here, is mandatory. As a corollary, it would appear that tropical analyses *not* produced under the control of synoptic climatology and thermodynamic restraints should *not* be used for tropical forecasting, nor should they be filed as "official analyses" to be used later by research organizations.

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